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Macroinvertebrate and Fish Populations in a Restored Impounded Salt Marsh 21 Years After the Reestablishment of Tidal Flooding

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ABSTRACT / During the last two decades, the State of Connecticut has restored tidal flow to many impounded salt marshes. One of the first of these and the one most extensively studied is Impoundment One in the Barn Island Wildlife Management Area in Stonington, Connecticut. In 1990, twelve years after the re-establishment of tidal flooding, the density of the marsh snail *Melampus bidentatus*, the numerically dominant macroinvertebrate of the high marsh, in Impoundment One was about half that in reference marshes below the breached impoundment dike. By 1999 the densities of *Melampus* above and below the dike were not significantly different, but the shell-free biomass was greater above the dike as a result of the somewhat larger number and size of the snails there. Twenty-one years after the renewal of tidal flooding, three marsh macroinvertebrates (the amphipods *Orchestia grillus* and *Uhlorchestia spartinophila* and the mussel *Geukensia demissa*) were significantly less abundant in the previously impounded marsh than in the reference marshes, whereas another amphipod (*Gammarus palustris*) was more abundant above the breached dike where conditions appeared to be somewhat wetter. In 1991 the fish assemblage in a mosquito-control ditch in Impoundment One was similar to that in a ditch below the breached dike; however, the common mummichog *Fundulus heteroclitus* appeared to be less abundant in the restoring marsh. By 1999 the number of mummichogs caught in ditches was significantly greater in Impoundment One than in the reference marsh, but the numbers of mummichogs trapped along the tidal creek were comparable above and below the dike. The results obtained in this study and those of other restoring marshes at Barn Island indicate the full recovery of certain animal populations following the reintroduction of tidal flow to impounded marshes may require up to two or more decades. Furthermore, not only do different species recover at different rates on a single marsh, but the time required for the recovery of a particular species may vary widely from marsh to marsh, often independently of other species.

Impoundment of marshes with the reduction or elimination of tidal flooding often results in striking changes in marsh vegetation. In many cases, *Phragmites australis* (common reedgrass), or less frequently *Typha angustifolia* (narrow-leaved cattail), becomes established at the expense of typical marsh grasses and forms a dense monoculture. Such change alters the physical habitat of the marsh and may influence food resources for consumers (Roman and others 1984, Niering 1997). Although little direct information exists concerning the effects of impoundment on marsh fauna, it seems highly probable that the populations of many/most tidal marsh macroinvertebrates and fishes are adversely affected, if not exterminated (Fell and others 1991). In addition, use of impounded marshes by birds that are largely restricted to short-grass marshes and by larger species of waterfowl, shorebirds and wading birds is reduced (Rozsa 1995, Brawley and others 1998, Benoit and Askins 1999).

Along the Atlantic coast of North America many salt marshes have been degraded as a result of tidal restriction, as well as by other impacts of coastal development (Niering 1997). During the past century about 30% of Connecticut's tidal salt marshes were degraded or lost (Rozsa 1995). However, in 1969 Connecticut adopted the Tidal Wetlands Act that has effectively preserved the state's remaining tidal marshes. In addition, the Coastal Management Act of 1980 has led to the resto-

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ration of many degraded wetlands (Rozsa 1995, Warren and others 2001).

In a number of cases, the re-establishment of tidal flow to tidally restricted marshes alone has ultimately led to a high degree of recovery. Much of the *Phragmites* and/or *Typha* gradually disappears and typical salt marsh plants colonize the area (Warren and others 2001). Although the restoration of marsh vegetation has been well documented, recovery of marsh fauna has received far less attention (Rozsa 1995, Niering 1997). The Barn Island marsh complex in Stonington, Connecticut provides a good example of marsh degradation due to tidal restriction followed by restoration. Four of five valley marshes within this complex were impounded during the late 1940's in an attempt to increase waterfowl habitat. Proceeding from west to east, Impoundment One converted primarily to a *Typha angustifolia*-dominated brackish marsh, Impoundments Two and Three changed to largely unvegetated mudflats with standing water, and Impoundment Four became dominated by *Phragmites*. These impounded marshes were reopened to tidal flooding at different times by placement of culverts in the impoundment dikes and are now in various stages of restoration. Tidal flushing was renewed to Impoundments One and Two in 1978, to Impoundment Four in 1987, and to Impoundment Three in 1991. Tidal flow to Impoundment One was further increased in 1982.

The recovery of Impoundment One has been most extensively studied. By 1988, ten years after the re-establishment of tidal flow, *Typha* cover had declined dramatically and much of the remaining *Typha* was stunted. *Spartina alterniflora* (smooth cordgrass) had increased from a few plants near the dike to cover almost half of the marsh surface; and high marsh species including *S. patens* (saltmeadow cordgrass), *Distichlis spicata* (spikegrass), *Juncus gerardii* (blackgrass), and forbs had become reestablished (Sinicrope and others 1990, Barrett and Niering 1993). By the early 1990's, a characteristic assemblage of macroinvertebrates including *Melampus bidentatus* (snail), *Geukensia demissa* (mussel), *Orchestia grillus* (amphipod), *Uhlorchestia spartinophila* (amphipod), *Philoscia vittata* (isopod) and *Uca* spp. (fiddler crabs) had recolonized Impoundment One, but many of these animals were not quantitatively sampled (Fell and others 1991, Peck and others 1994). The mean density of *Melampus*, in this restoring marsh was not significantly different from that in all the studied bay front marsh areas below the impoundment dike (Fell and others 1991). However, it was only 53% of the mean snail density in the marshes directly below the dike (western part of Headquarters Marsh next to the tidal creek and Palmer Neck Marsh), which appear to be the most appropriate reference marshes, and was also significantly lower than that in a nearby unimpounded marsh (Davis Marsh) of about the same size (Peck and others 1994). In 1991, limited sampling indicated that a typical assemblage of tidal marsh fishes was present in Impoundment One; essentially the same species of fish occurred in Impoundment One as were present in the reference marsh below the dike and in the unimpounded Davis Marsh (Allen and others 1994, Fell and others 2000). However, *F. heteroclitus*, the numerically dominant species at all sites, appeared to be less abundant in Impoundment One than in the reference marshes. Finally, use of Impoundment One by wetland birds was extensive and use by short-grass marsh specialists (saltmarsh sharp-tail sparrow and seaside sparrow) was apparently greater than that of the reference marsh below the dike by the mid-1990's (Brawley and others 1998). Collectively these studies suggest that Impoundment One is in an advanced stage of restoration but still different in a number of ways from marshes that have never been impounded.

It should be noted that one of the reference marshes below Impoundment One (Headquarters Marsh) has also undergone considerable vegetation change during the last fifty years. *Spartina patens*, formerly the dominant plant species of the high marsh, and *Juncus gerardii* have decreased in abundance, whereas *S. alterniflora* and forb cover have dramatically increased. These changes appear to be related to increasing rates of relative sea level rise (Warren and Niering 1993).

The goal of the present study was to examine macroinvertebrate and fish populations in Impoundment One twenty one years after the dike was breached, comparing them to those in reference marshes directly below the dike. Data from the present study will also be compared with those obtained from the same marshes in 1990 and 1991 (Fell and others 1991, Allen and others 1994), as well as with data on the restoration of other previously impounded marshes at Barn Island, in order to assess rates and patterns of recovery. Some of the results of this study have been presented in preliminary form as part of a comprehensive review of marsh restoration in Connecticut (Warren and others 2001).

Site Description

The study sites are part of the Barn Island Wildlife Management Area situated on Little Narragansett Bay in Stonington, Connecticut, at the eastern end of Long Island Sound (Figure 1). There are five valley marshes within this state-owned complex and a sixth valley marsh in private ownership is located just to the east of them. During the 1930's the marsh system was exten-

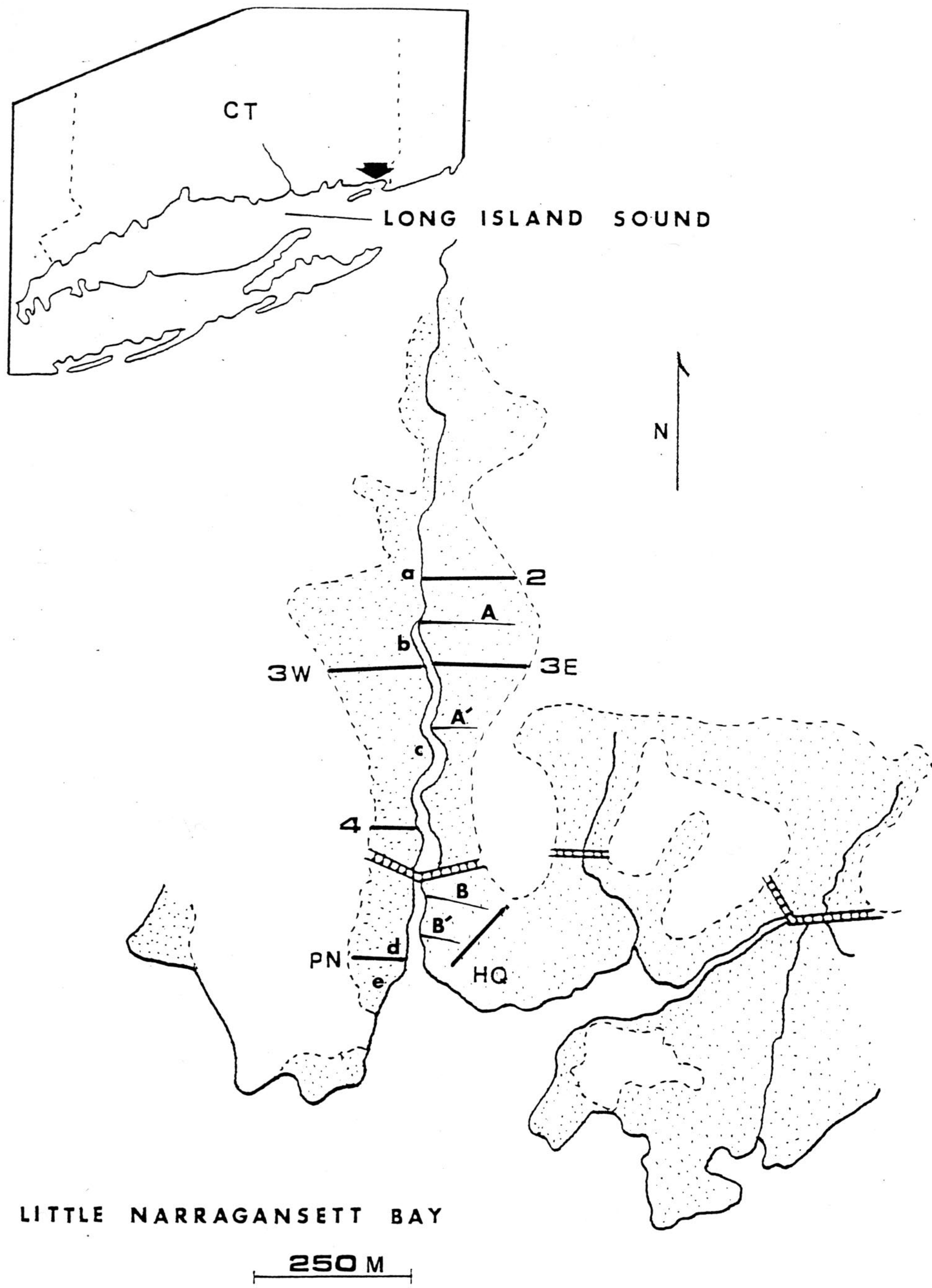

Figure 1. Site map of Impoundment One and associated tidal marshes within the Barn Island Wildlife Management Area. Invertebrate sampling transects 2, 3E, 3W, and 4 are in restoring Impoundment One; transects PN (Palmer Neck) and HQ (Headquarters) are in reference marshes below the breached dike. Mosquito-control ditches in which fish were trapped are indicated by upper case letters (A and A^1 in Impoundment One and B and B^1 in the Headquarters Marsh). Sites where fish were trapped along the tidal creek are indicated by lower case letters (a–e). Inset (upper left) shows the location of the Barn Island marshes in Stonington, Connecticut (arrow).

sively ditched for mosquito control with the aim of draining standing water from the marsh surface. Beginning in 1946 the four westernmost valley marshes were impounded by earthen dikes. This project was carried out by the Connecticut Board of Fisheries and Game to offset the loss of waterfowl habitat as a result of mosquito-control ditching. The shallow water, essentially nontidal habitats created upstream of the dikes at first attracted waterfowl. However, some of these regions became densely colonized by salt-intolerant plants, especially *Typha angustifolia* and *Phragmites australis*, and waterfowl use declined (Rozsa 1995). Impoundment One, the focus of the present study, has an area of 21 ha. Following severe restriction of tidal flow, it became a *Typha*-dominated wetland. However, two large mudflats, one on each side of the tidal creek, with a combined area of 3.8 ha developed about 400 m above the dike. Although no studies of benthic invertebrates or fishes were made in this *Typha* marsh, it seems unlikely that typical salt marsh animals existed there. Frogs were common and snapping turtles and water snakes were present (Hebard 1976). Impoundment One was reconnected to the adjacent estuary in 1978 by breaching the dike with a 1.5 m diameter culvert, and in 1982 a 2.1 m diameter culvert was added to nearly restore full tidal flow.

Marshes immediately below the breached dike served as references for assessing the recovery of Impoundment One. Palmer Neck Marsh is situated to the west of the tidal creek and Headquarters Marsh is located to the east of it (Figure 1).

The mean tidal range in Little Narragansett Bay is 0.82 m and the salinity varies from about 28‰ to 32‰ (Sinicrope and others 1990).

Methods

The distribution and abundance of six macroinvertebrate species, *Melampus bidentatus*, *Geukensia demissa*, *Orchestia grillus*, *Uhlorchestia spartinophila*, *Gammarus palustris*, and *Philoscia vittata*, were determined by counting animals within 0.25 m^2 quadrats situated 5 m apart along transects that extended across the marsh (Figure 1). The transects were the same used in a 1990 study (Fell and others 1991), but not all of the transects sampled in the earlier study were re-sampled in the present one. For comparisons between the two studies, only data from transects sampled during both years were used. A total of 136 quadrats along six transects were sampled. Transects in Impoundment One and the reference marshes were alternately sampled during the study period that extended from 26 May through 8 July 1999.

Animals were collected using a 50-cm-square wooden frame, 9 cm high, that was placed on the surface of the marsh and anchored at each corner with a 36-cm-long steel chaining pin. The percent cover of different plant species was visually estimated; and then after the vegetation within the frame was examined for the presence of animals, it was clipped at the bases of the stems to facilitate collection of animals in the litter and on the surface of the peat. An attempt was made to capture all of the macroinvertebrates observed within the quadrats, but a few of the more active animals were able to escape. Such loss was minimized by collecting from the periphery of the quadrats toward the center, with two or three people working on each quadrat. Snails and mussels were kept alive and later returned to the marsh; all other invertebrates were preserved immediately in 95% ethanol to facilitate sorting and counting.

Snail shell lengths were measured to the nearest millimeter for determining size distributions. Shell-free dry weights for different sized *Melampus* were obtained by drying the soft tissues at 100°C until constant weights were reached. These values were then used to calculate biomass, using the following shell-free dry weight (y) vs. shell length (x) regression equation:

$$y = 2.24 - 0.27x + 0.23x^2 (n = 24, R^2 = 0.98).$$

The salinity of the soil water was determined at each quadrat site by squeezing water from a sample of peat, filtering the water through Whatman 1 filter paper, and measuring the salinity with a Goldberg refractometer (American Optical Corp.).

Fishes and macrocrustaceans in mosquito-control ditches and the tidal creek (Figure 1) were sampled using unbaited Gee minnow traps (Smith and Able 1994, Halpin 1997). Three traps situated about 10 m apart were set at each site during each sampling day and left approximately 24 hours. Animals caught in the traps were identified and enumerated in the field and then released. Trapping usually took place at about one-week intervals from 2 February through 11 November 1999 for a total of 33 trapping days. In all 604 traps were set. Some of the sites in Impoundment One and Headquarters Marsh were sampled throughout this period; others were sampled from 25 May through 27 July.

On 24 October 1999, fishes using the flooded marsh surface were sampled with unbaited Plexiglas Breder traps (Breder 1960). These traps had a 28-cm-wide funnel opening. Trap lines were placed parallel to and about 3 m back from the banks of mosquito-control ditches (ditch A in Impoundment One and ditch B in the Headquarters Marsh, Figure 1). Each trap line consisted of eight traps situated 5 m apart. Individual trap sites were cleared of vegetation by clipping plants at the surface of the peat, and the traps were held firmly in place with steel chaining pins. Before the marsh was flooded, the traps were set out with the mouths facing

Table 1. Mean percent cover and frequency of occurrence (%) of dominant angiosperms in the sample quadrats in Impoundment One and the reference marshes (Headquarters and Palmer Neck) below the dike during 1999

	Impoundment One (n = 76)		Headquarters and Palmer Neck (n = 60)	
Species	Cover	Frequency	Cover	Frequency
Spartina alterniflora	40	92	28	75
Spartina patens	10	30	27	68
Distichlis spicata	10	38	8	52
Juncus gerardii	<1	3	15	33
Iva frutescens			1	2
Phragmites australis	<1	1		
Scirpus robustus			<1	2
Forbs[a]	6	47	5	60

[a] Broad-leaved, herbaceous plants.

away from the ditches. The traps were emptied as soon as the water was off the marsh surface.

During each fish trapping day, bottom water temperature and salinity were measured in the tidal creek at two stations: near mosquito-control ditch A in Impoundment One and at the opening of mosquito-control ditch B in the Headquarters Marsh.

For paired comparisons of specific species abundances between restoring Impoundment One and the combined reference marshes or between the two references marshes, separate t-tests and, when appropriate, non-parametric Mann-Whitney tests were used. Analysis of variance (one-way ANOVA) followed by the multiple-range Tukey test was employed for multiple comparisons among the four transects in Impoundment One and for determining the effect of season on fish abundance. When the assumptions for ANOVA were not met, we used the non-parametric Kruskal-Wallis test and the post hoc Dunn test.

Results

Vegetation

Spartina alterniflora (saltwater cordgrass) was the most abundant angiosperm in the 76 sample quadrats in Impoundment One (Table 1). This grass occurred in 92% of the quadrats and dominated 37% of them. *Spartina patens* (saltmeadow cordgrass) and *Distichlis spicata* (spikegrass) each was present in approximately one third of the quadrats and represented about 10% of the cover. Forbs, especially *Plantago maritima* (seaside plantain), *Limonium nashii* (sea lavender), *Aster tenuifolius* (salt-marsh aster), and *Salicornia europaea* (saltwort), provided a small fraction of the plant cover, although they were present in nearly half of the quadrats. *Spartina patens, Distichlis,* and forbs were especially common near the tidal creek.

The 60 sample quadrats in the Headquarters and Palmer Neck reference marshes were co-dominated by *S. alterniflora* and *S. patens*. Each of these grasses was present in about 70% of the quadrats and accounted for nearly 30% of the cover. Some quadrats were dominated by one or the other of the *Spartina* species, whereas others contained a substantial mixture of both (Table 1). *D. spicata, J. gerardii,* and forbs were present in smaller amounts. The dominant forbs were generally the same ones that occurred in Impoundment One; however, *Triglochin maritima* (arrow-grass) tended to be more abundant in the reference marshes.

Ruppia maritima (widgeon grass) was present in the sampled mosquito-control ditches and tidal creek above the dike. This plant also occurred very sparsely in shallow pools on the marsh surface of Impoundment One.

Macroinvertebrates

The densities of the studied macroinvertebrates in the two reference marshes (Headquarters and Palmer Neck) below the breached dike were similar (Table 2). Only *Genkensia demissa* exhibited a significant difference in abundance between the two marshes. Consequently, for comparisons with breached Impoundment One, these marshes were generally considered as one.

The abundances of some of the macroinvertebrates were more varied in Impoundment One, their densities differing among the four transects (Table 3). *Melampus bidentatus* densities were not significantly different among transects 3E, 3W and 4, but this snail was more abundant along transect 2 than along transects 3E and 3W. The densities of *Uhlorchestia spartinophila* along transects 2 and 3E did not differ from those of any of the other transects; however, its density along transect 3W was higher than along transect 4. Finally, *Gammarus*

Table 2. Mean densities (No. ± SE/m^2) of six macroinvertebrates along a transect in Headquarters Marsh (HQ) and a transect in the Palmer Neck Marsh (PN), both reference marshes situated below Impoundment One at Barn Island

	Transect		
Species	HQ (n = 35)	PN (n = 25)	Significance
Melampus bidentatus	471 ± 72	513 ± 90	t-test, $t = -0.364$, $df = 58$, $P = 0.717$
Geukensia demissa	6.3 ± 1.7	1.3 ± 0.6	Mann-Whitney, $z = -2.454$, $P = 0.014$
Orchestia grillus	37.4 ± 10.2	38.4 ± 11.9	Mann-Whitney, $z = -0.973$, $P = 0.330$
Uhlorchestia spartinophila	122.2 ± 25.3	99.8 ± 23.3	t-test, $t = 0.623$, $df = 58$, $P = 0.536$
Gammarus palustris	8.4 ± 3.8	1.3 ± 0.9	Mann-Whitney, $z = -0.736$, $P = 0.462$
Philoscia vittata	14.3 ± 7.1	21.8 ± 10.3	Mann-Whitney, $z = -0.113$, $P = 0.910$

Table 3. Mean densities (No. ± SE/m^2) of six macroinvertebrates along four transects in breached Impoundment One at Barn Island. Values followed by the same letter are not significantly different

	Transect				
Species	2 (n = 11)	3E (n = 26)	3W (n = 23)	4 (n = 16)	Significance
Melampus	1014 ± 107a	360 ± 75b	560 ± 71b	690 ± 173a,b	ANOVA, $F = 5.799$, $P = 0.001$; Tukey < 0.05
Geukensia	8.0 ± 7.2	0.3 ± 0.2	1.2 ± 0.7	5.8 ± 3.5	Kruskal-Wallis, $\chi^2 = 2.488$, $P = 0.478$
Orchestia	7.6 ± 6.5	8.2 ± 2.4	11.8 ± 2.8	13.8 ± 5.4	Kruskal-Wallis, $\chi^2 = 3.339$, $P = 0.342$
Uhlorchestia	83.3 ± 22.0a	66.2 ± 14.1a	93.9 ± 18.2a,b	22.3 ± 9.5a,c	ANOVA, $F = 3.372$, $P = 0.023$, Tukey < 0.05
Gammarus	8.4 ± 4.0a	62.2 ± 20.2a	68.5±14.2a,b	5.2 ± 4.5a,c	Kruskal-Wallis, $\chi^2 = 13.319$, $P = 0.004$, Dunn < 0.05
Philoscia	1.8 ± 1.0	2.2 ± 1.1	4.4 ± 2.8	7.8 ± 4.1	Kruskal-Wallis, $\chi^2 = 2.241$, $P = 0.524$

palustris was also more numerous along transect 3W than along transect 4.

Melampus bidentatus was widely distributed in the studied marshes, occurring in 89% of the 136 sample quadrats (Table 4). Its mean density in Impoundment One was not different from that in the reference marshes immediately below the dike ($t = 1.190$, $df = 134$, $P = 0.263$). Within Impoundment One *Melampus* tended to be more abundant in areas dominated by *Spartina*(*Spartina alterniflora* or *S. patens*) than in other vegetated regions of the marsh, but this difference was not significant ($t = 1.690$, $df = 67$, $P = 0.96$). On the other hand, within the reference marshes this snail was more numerous in *S. alterniflora*-dominated areas and mixtures of *S. alterniflora* and *S. patens* (considered together) than in other types of vegetation including thick *S. patens* ($t = 4.212$, $df = 58$, $P < 0.001$).

In both Impoundment One and the reference marshes, the modal shell length of *Melampus* was 8.1–9.0 mm (Figure 2). However, 73% of the snails were greater than 8.0 mm in shell length in Impoundment One compared with 61% in the reference marshes. Furthermore, the shell-free biomass of *Melampus* was significantly greater in Impoundment One: 7.17 ± 0.63 g dry wt/m^2 in Impoundment One compared with 5.35 ± 0.56 g dry wt/m^2 in the Headquarters and Palmer Neck reference marshes ($t = 2.148$, $df = 134$, $P = 0.034$).

Melampus was reproducing in Impoundment One and the reference marshes. Egg masses, occasionally in large numbers, were observed in 42% of the sample quadrats in Impoundment One and 23% of those in the Headquarters and Palmer Neck Marshes.

Geukensia demissa occurred at moderate frequencies on the studied marshes (Table 4). However, the density of this mussel in Impoundment One was significantly lower than in the reference marshes (Mann-Whitney, $Z = -2.648$, $P = 0.008$). As mentioned earlier, the densities of *Geukensia* differed in the two reference marshes. Although the density of *Geukensia* in Impoundment One was lower than that in Headquarters Marsh (Mann-Whitney, $Z = -3.568$, $P < 0.001$), it was not significantly different from that in Palmer Neck Marsh (Mann-Whitney, $Z = -0.289$, $P = 0.772$).

The isopod *Philoscia vittata*, which was patchily distributed, tended to be less abundant in Impoundment

Table 4. Frequency of occurrence (%) and mean densities (No. ± SE/m^2) of *Melampus bidentatus* and *Geukensia demissa* in Impoundment One and the reference marshes (Headquarters and Palmer Neck) below the dike 21 years after reestablishment of tidal flow to Impoundment One

		Melampus		*Geukensia*	
Marsh Region	No. Quadrats	% Occurrence	Density	% Occurrence	Density
Impoundment One					
S. alterniflora-dominated[a]	28	100	743 ± 86	18	3.6 ± 2.9
Sparse *S. alterniflora*	13	92	515 ± 136	8	0.3 ± 0.3
S. patens-dominated	5	100	750 ± 174	20	0.8 ± 0.8
Other high marsh	23	96	573 ± 107	26	4.7 ± 2.5
Pool	7	—	—	—	—
All areas	76	88	584 ± 56	17	2.8 ± 1.3
Headquarters, Palmer Neck					
S. alterniflora-dominated	12	92	690 ± 111	58	6.0 ± 2.6
S. alterniflora/S. patens	13	85	776 ± 167	54	6.8 ± 2.5
S. patens-dominated	14	86	300 ± 84	36	4.9 ± 3.1
Juncus-dominated	9	100	380 ± 75	22	1.3 ± 0.9
Other high marshes	12	92	278 ± 72	8	1.0 ± 1.0
All areas	60	90	489 ± 56	37	4.2 ± 1.1

[a]Species covered at least 55% of quadrat.

One than in the reference marshes (Table 5), but the difference in densities was not significant (Mann-Whitney, $Z = -1.899$, $P = 0.058$). All of the other peracarid crustaceans were present at significantly different densities in the marshes above and immediately below the dike. *Orchestia grillus* and *Uhlorchestia spartinophila* were less abundant (Mann-Whitney, $Z = -4.167$, $P = <0.001$ and $t = 2.457$, $df = 134$, $P = 0.015$ respectively), whereas *Gammarus palustris* was more abundant (Mann-Whitney, $Z = -4.067$, $P = <0.001$) in Impoundment One. However, the mean densities of all the crustaceans combined were not significantly different in Impoundment One and the reference marshes ($t = 1.932$, $df = 134$, $P = 0.56$).

Philoscia occurred at moderate frequencies in most areas of the studied marshes where its mean density tended to be lowest in areas dominated by *S. alterniflora*. This isopod was absent from regions of Impoundment One with a sparse cover of *S. alterniflora*. On the other hand, *Gammarus* was particularly abundant in *S. alterniflora*-covered regions of Impoundment One. This amphipod was not found in *S. patens*-dominated areas of Impoundment One or in mixed high marsh vegetation of the reference marshes. *Orchestia* was moderately abundant throughout the reference marshes and in the more thickly vegetated areas of Impoundment One, and *Uhlorchestia* occurred at relatively high densities in most parts of the restored marsh and all regions of the reference marshes.

The soil water salinities of the sample quadrats in Impoundment One and the reference marshes were similar. The mean soil water salinity for Impoundment One was 33.2 ± 0.8‰ (range = 14‰ to 45‰) and

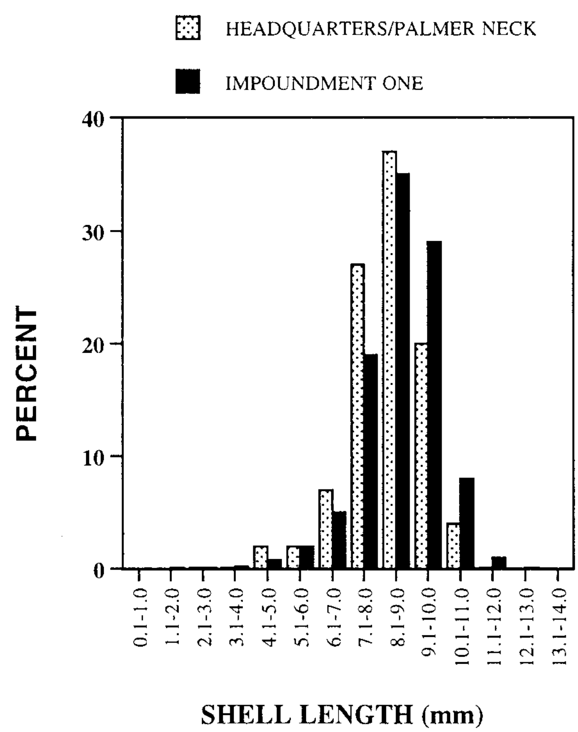

Figure 2. Size frequency distribution of *Melampus bidentatus* in Impoundment One (N = 11,104 snails) and the reference marshes (Headquarters and Palmers Neck) below the dike (N = 7329 snails).

Table 5. Frequency of occurrence (%) and mean density (No. ± SE/m^2) of *Philoscia vittata*, *Orchestia grillus*, *Uhlorchestia spartinophila*, and *Gammarus palustris* in Impoundment One and the reference marshes (Headquarters and Palmer Neck) 21 years after reestablishment of tidal flow to Impoundment One

		Philoscia		*Orchestia*		*Uhlorchestia*		*Gammarus*	
Marsh Region	No. quadrats	% occur.	density	% occur.	density	% occur.	density	% occur.	density
Impoundment One									
S. alterniflora-dominated[a]	28	18	1.1 ± 0.5	39	10.6 ± 2.8	93	84.6 ± 13.1	79	93.7 ± 18.6
Sparse *S. alterniflora*	13	0	0	23	1.2 ± 0.7	77	47.7 ± 18.8	54	37.8 ± 15.0
S. patens-dominated	5	100	15.2 ± 4.8	80	30.4 ± 13.0	60	18.4 ± 11.8	0	0
Other high marsh	23	39	8.3 ± 3.7	70	14.1 ± 3.6	83	90.3 ± 18.0	17	10.8 ± 6.0
Pool	7	—	—	—	—	—	—	—	—
All areas	76	25	4.0 ± 1.3	45	10.4 ± 1.9	76	67.8 ± 8.6	45	44.3 ± 8.7
Headquarters, Palmer Neck									
S. alterniflora-dominated	12	8	0.7 ± 0.7	67	17.0 ± 5.9	100	217.7 ± 58.5	8	3.3 ± 3.3
S. alterniflora/S. patens	13	23	4.9 ± 3.1	85	34.8 ± 13.4	100	99.7 ± 24.2	31	9.5 ± 5.0
S. patens-dominated	14	57	8.0 ± 2.8	79	12.9 ± 4.2	93	58.9 ± 17.8	14	3.7 ± 2.9
Juncus-dominated	9	44	28.0 ± 13.3	100	128.0 ± 31.9	78	72.9 ± 37.8	22	12.4 ± 11.9
Other high marsh	12	50	50.7 ± 25.9	75	23.3 ± 8.2	83	115.3 ± 39.1	0	0
All areas	60	37	17.4 ± 5.9	80	37.8 ± 7.7	92	112.9 ± 17.6	15	5.5 ± 2.3

[a]Species covered at least 55% of quadrat.

Table 6. Density (No. ± SE/m^2) and shell-free biomass (g dry wt/m^2) of *Melampus bidentatus* in Impoundment One and the reference marshes (Headquarters and Palmer Neck) below the dike in 1990 and 1999. N = number of sample quadrats

	1990			1999		
Marsh	*N*	Density	Biomass	*N*	Density	Biomass
Impoundment One	74	358 ± 42	5.26 ± 0.53	76	584 ± 56	7.17 ± 0.63
Headquarters/Palmer	54	624 ± 66	5.08 ± 0.51	60	489 ± 56	5.35 ± 0.56

that for the reference marshes was 34.7‰ ± 1.1‰ (range = 15‰ to 59‰).

Comparison of Molluscs in 1990 and 1999

The density of *Melampus* in Impoundment One after twelve years of restored tidal flow (Table 6) was significantly lower than in the reference marshes ($t = 3.351$, $df = 126$, $P = 0.001$), but the shell-free biomass was not ($t = 0.351$, $df = 126$, $P = 0.726$). In 1990, as in 1999, the densities of *Melampus* in the Headquarters Marsh and Palmer Neck Marsh were not significantly different ($t = 0.93$, $df = 52$, $P = 0.926$). Although the densities and biomasses of *Melampus* in these reference marshes (considered together) were not different in 1990 and 1999 (Table 6) ($t = 1.574$, $df = 112$, $P = 0.118$ and $t = 0.262$, $df = 112$, $P = 0.794$, respectively), the mean density and biomass of this snail in Impoundment One increased significantly between these years ($t = 3.194$, $df = 148$, $P = 0.002$ and $t = 2.158$, $df = 148$, $P = 0.033$, respectively).

The densities of *Geukensia* in high marsh areas of Impoundment One and the combined reference marshes were not significantly different in 1990 (Mann-Whitney, $Z = -1.097$, $P = 0.273$). Furthermore, the densities of this mussel were not different in the two reference marshes (Mann-Whitney, $Z = -1.544$, $P = 0.123$). There was no significant change in the abundances of *Geukensia* in Impoundment One or in the combined reference marshes between 1990 and 1999 (Mann-Whitney, $Z = -0.319$, $P = 0.749$ and $Z = -1.675$, $P = 0.094$, respectively).

Fishes

Of the 53,295 fish trapped in the tidal creek and mosquito-control ditches in Impoundment One and the reference marsh, 50,890 (95%) were *Fundulus heteroclitus* (Table 7). The mean number of *F. heteroclitus* caught per trap per day in mosquito-control ditches (Table 8) was significantly greater in Impoundment One than in the reference marsh ($t = 2.818$, $df = 32$,

Table 7. Total numbers of fishes and crustaceans caught in unbaited minnow traps placed within mosquito-control ditches and along the tidal creek in Impoundment One and the Headquarters Marsh below the dike at Barn Island, Connecticut in 1999 (see map)

	Ditches				Creek				
	Impoundment One		*Headquarters*		*Impoundment One*			*Headquarters*	
Species	A	A′*	B	B′*	a*	b	c	d*	e
Fundulus heteroclitus	11,764	4240	9593	3491	1330	6805	5948	1199	6520
Cyprinodon variegatus	774	360	181	30	8	35	59	14	28
Apeltes quadracus	33		110			57	60	2	256
Anguilla rostrata	63	5	25	4	45	34	17	3	6
Fundulus luciae	69	11	1			1			
Alosa sapidissima									31
Fundulus majalis	7	5	6	6		3	6	11	4
Pungitius pungitius	7						2		1
Lucania parva	4		1						3
Menidia menidia	2			1		2			2
Gasterosteus aculeatus	2		2			2			
Caranx hippos									3
Pholis gunnellus			1						1
Myonocephalus scorpius			1						
Syngnathus fuscus									1
Carcinus maenas	22	9	42	14	3	13	12	2	25
Callinectes sapidus					1	2	2	1	4
Hemigrapsus sanguineus									2
Uca pugnax	2								
Cancer irroratus					1		1		1
Palaemonetes pugio‡	71	453	336	323	269	262	79	119	322
Crangon septemspinosa‡									1

*Sampled May 25 to July 27.
‡Enumerated beginning May 25.

Table 8. Mean numbers ± SE of *Fundulus heteroclitus* caught per trap per day in mosquito-control ditches and the tidal creek in Impoundment One and a reference marsh below the dike. Fish were sampled 33 times over a period extending from 2 February to 11 November 1999

Marsh	Mosquito-control ditches	Tidal creek
Impoundment One	127 ± 8	62 ± 3
Headquarters	101 ± 6	61 ± 5

P = 0.008); however, the mean numbers caught per trap per day in regions of the tidal creek above and below the dike were not significantly different (t = 0.228, df = 32, P = 0.821). Trap captures of *F. heteroclitus* tended to be lowest during the winter (Figure 3) when water temperatures dropped to as low as 0.5°C and ice was sometimes present. The mean number of *F. heteroclitus* caught per trap per day in the creek was significantly lower during the winter than at other times of the year (ANOVA, F = 26.462, P = <0.001, Tukey, P < 0.05), and the number caught in the ditches in winter was lower than during the spring and fall (ANOVA, F = 5.701, P = 0.003, Tukey, P < 0.05).

Table 9. Numbers of fishes and crustaceans caught in Breder traps on the flooded marsh surface of Impoundment One and Headquarters Marsh during an ebbing tide on 24 October 1999. Eight traps were placed in each marsh. The mean number per trap ± SE is given in parentheses for the more abundant species

Species	Impoundment One	Headquarters Marsh
Fundulus heteroclitus	154 (19.3 ± 2.6)	152 (19.0 ± 3.4)
Menidia menidia	11 (1.4 ± 0.8)	89 (11.1 ± 4.4)
Cyprinodon variegatus	65 (8.1 ± 1.6)	14 (1.8 ± 1.0)
Fundulus majalis	5	10
Lucania parva	2	4
Alosa sapidissima		1
Palaemonetes pugio		6
Carcinus maenas		1
Hemigrapsus sanguineus		1

The mean species richness of fish caught in the creek and ditches of Impoundment One (3.67 ± 1.05)

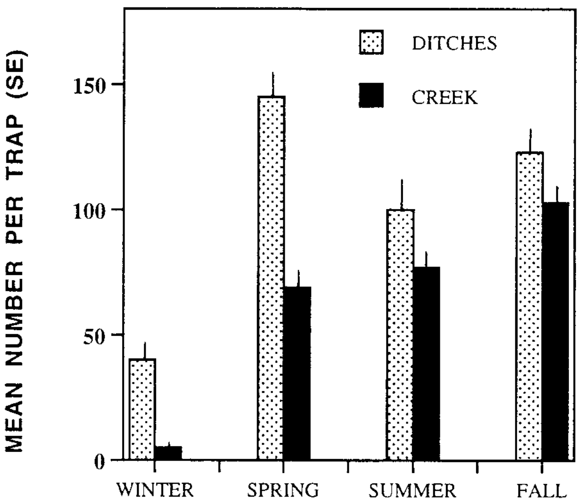

Figure 3. Seasonal abundance (mean number ±SE/trap/day) of *Fundulus heteroclitus* in mosquito-control ditches and a tidal creek at Barn Island. Data from Impoundment One and the Headquarters Marsh were combined.

and the Headquarters Marsh (3.55 ± 1.12) were not significantly different ($t = 0.56$, $df = 32$, $P = 0.580$). A total of 10 species of fish were captured in Impoundment One compared with 15 species in the reference marsh (Table 7). Except for *Alosa sapidissima* (American shad), the species not caught in Impoundment One were very rare; and large *A. sapidissima* were observed swimming out of Impoundment One through the largest culvert in the dike. *Cyprinodon variegatus* (sheepshead minnow), *Anguilla rostrata* (American eel), and *Fundulus luciae* (spotfin killifish) tended to be more numerous in Impoundment One, whereas *Apeltes quadracus* (fourspine stickleback) tended to be more abundant below the impoundment.

Seven species of macrocrustaceans were included in the trap catch, five in Impoundment One and six below the dike. Of these only *Carcinus maenas* (green crab) and *Palaemonetes pugio* (grass shrimp) were common. *P. pugio* and *Crangon septemspinosa* (sand shrimp) were not enumerated until 25 May, but both of these shrimp were present in Impoundment One and the reference marsh during the winter and early spring. The introduced Japanese rock crab, *Hemigrapsus sanguineus*, was caught at the mouth of the tidal creek on two occasions.

Fishes and crustaceans were caught in Breder traps on the flooded marsh surface of Impoundment One and the Headquarters Marsh during a perigee spring tide in late October. The mean numbers per trap of *F. heteoclitus* caught in the restoring and reference (Headquarters) marshes were not significantly different ($t = 0.58$, $df = 14$, $P > 0.95$). More *Cyprinodon* were caught in Impoundment One than in the Headquarters Marsh (Mann-Whitney, $Z = -2.810$, $P = 0.005$) whereas a greater number of *Menidia* were trapped below the dike (Mann-Whitney, $Z = -2.041$, $P = 0.041$).

The salinity of the tidal creek above the impoundment dike was often somewhat lower than that below it and was lowest during the winter. The mean salinity near ditch A above the dike was 20.9 ± 1.4‰ (range = 1‰ to 32‰), whereas the salinity at ditch B below the dike was 25.1 ± 0.9‰ (range = 8‰ to 31‰).

Discussion

Connecticut's approach to the restoration of impounded tidal salt marshes is based on the premise that reestablishment of tidal flow is sufficient to set in motion a natural process of recovery (Rosza 1995, Warren and others 2001). An appropriate flooding regime suppresses or eliminates *Phragmites* and *Typha* and creates conditions that are favorable for recolonization by salt-marsh angiosperms, invertebrates, fish, and birds (Fell and others 2000, Warren and others 2001). A good example of such recovery is provided by Impoundment One in the Barn Island Wildlife Management Area, one of the first marshes in Connecticut to be restored.

When attempting to evaluate the recovery of an impounded marsh following the restoration of tidal flow, one is faced with the problem of an appropriate reference standard (Peck and others 1994). Often there are no detailed studies of the marsh prior to its impoundment. This is especially true with respect to animal populations. Even when such studies exist, comparison of the recovering marsh with the marsh prior to its impoundment may not be entirely valid. For example, if the pre-impoundment study was conducted many years earlier, it is likely that the marsh would have changed to some degree over a period of several decades even had it not been impounded. Here we chose to compare a recovering impounded marsh with marshes situated immediately below the breached impoundment dike, marshes that have also undergone marked vegetational changes during the last 50 years (Warren and Niering 1993). The changes in the reference marshes appear to have been driven in large part by natural processes, including relative sea level rise. Because of such processes, it seems unrealistic to expect that a recovering marsh will revert exactly to its former condition even under the best of circumstances.

An existing reference marsh(s) is also valuable for other reasons. Populations of organisms may exhibit large inter-annual variation which can confound comparisons over time when assessing the recovery of a degraded marsh, especially when sampling is infrequent. However, this problem is minimized by also comparing the recovering marsh to a suitable, nearby reference marsh that is subject to the same sorts of variation. Obviously since seasonal variation in populations of organisms also occurs, sampling must take place at the same time each year.

A comprehensive study of the vegetation in restoring Impoundment One was carried out in 1988, ten years after the re-establishment of tidal flooding (Sinecrope and others 1990, Barrett and Niering 1993). By that time *Typha* cover had decreased from 74% to 16%. Most of the remaining *Typha*, which was largely restricted to the upper reaches of the valley marsh, was stunted. On the other hand, *S. alterniflora* cover had increased from less than 1% to 45%; and *S. patens, Distichlis*, and *Juncus* had recolonized the area, each representing 5% or less of the marsh cover. During the first ten years of recovery, *Phragmites* cover, primarily along the upland border, increased from 6% to 17%; however, in most places its growth was stressed (0.3 to 1.5 m tall). Since 1988 saltmarsh angiosperms have increased to occupy approximately 85% of Impoundment One and *Phragmites* cover has declined (Fell and others 2000). The vegetation in the 76 sample quadrats of the present study is consistent with these observations.

In 1999, 21 years following the reestablishment of tidal flooding, the density of *Melampus* in Impoundment One was not significantly different from that in the reference marshes below the dike. However, the shell-free biomass was greater because of the somewhat larger number and size of snails in Impoundment One. The density of *Melampus* in Impoundment One after twelve years of restoration was significantly lower than in the reference marshes, but the shell-free biomass was not. At that time, 83% of the snails in Impoundment One were greater than 8mm in shell length compared with only 25% in the restoring marshes. A relatively small number of large snails appears to be characteristic of a number of restoring impounded marshes (Fell and others 1991, Peck and others 1994, Warren and others 2001). Although one of the reference marshes below Impoundment One (Headquarters Marsh) has undergone striking vegetational change during the last several decades (Warren and Niering 1993), the density and biomass of *Melampus* in the reference marshes did not change significantly between 1990 and 1999. However, the density of *Melampus* in the reference marshes tended to be somewhat lower in 1999 compared with 1990, and the snails appeared to be larger. Whether these differences simply represent year-to-year variation or indicate a trend can only be determined by future studies. On the other hand, both the mean density and

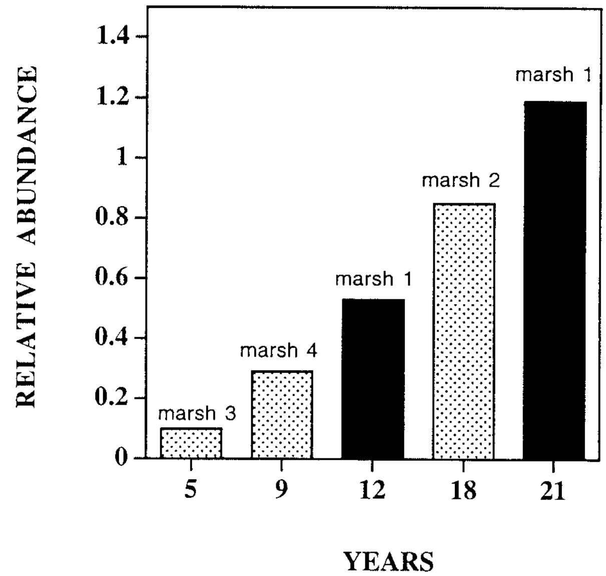

Figure 4. The relative abundance of *Melampus bidentatus* in impounded versus reference regions of four marshes at Barn Island (see descriptions in the introduction) in relation to the number of years since tidal flooding was re-established. The mean density of *Melampus* in each impounded marsh relative to that in the associated reference marsh below the breached impoundment dike (impounded/reference) is given. Impoundment One was studied in 1990 and 1999 and Impoundments Two, Three, and Four were studied in 1996. The data indicate a long trajectory for recovery.

biomass of *Melampus* in Impoundment One have increased significantly since 1990. It appears that the full recovery of *Melampus* populations on the restoring marshes at Barn Island is a slow process requiring as long as two decades, even though *Melampus* may recolonize a marsh within five years after the return of tidal flooding (e.g., Impoundment Three, Fell and others 2000). Figure 4 shows a trajectory for the recovery of *Melampus*, typically the numerically dominant macroinvertebrate of the high marsh and one that is widely distributed. In spite of the fact that these marshes differ from one another in ways other than years of restoration (e.g. elevation/hydroperiod), the data indicate a gradual recovery over time.

Geukensia occurred at lower densities in high marsh regions of Impoundment One than in such regions of the reference marshes. A 1991 study showed the mean densities and biomasses of *Geukensia* in low marsh areas along the tidal creek in Impoundment One and the creek in a nearby unimpounded marsh (Davis Marsh) were not significantly different (Peck and others 1994). At that time *Geukensia* was smaller and more numerous in the mosquito-control ditches in Impoundment One

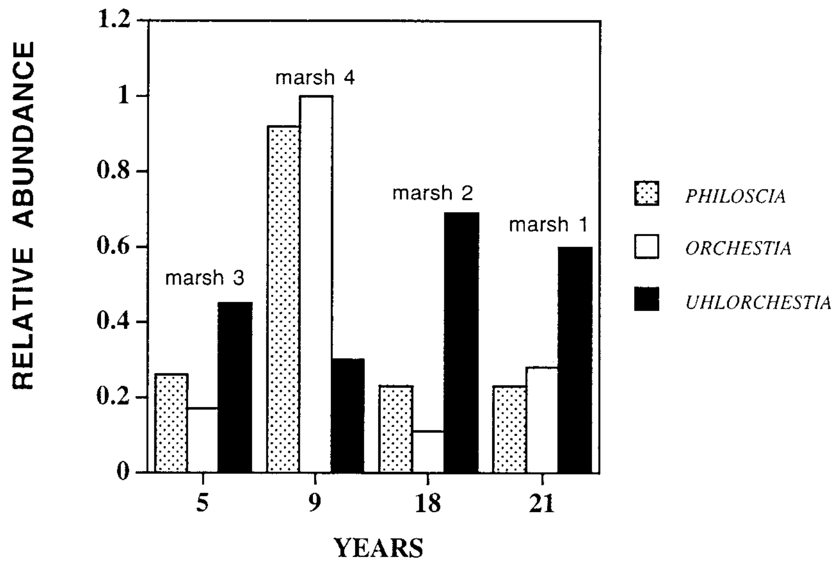

Figure 5. The relative abundances of three high marsh crustaceans in impounded vs. reference regions of four marshes at Barn Island (see descriptions in the introduction) in relation to the number of years since tidal flooding was re-established. The mean density of each crustacean in each impounded marsh relative to that in the associated reference marsh below the breached impoundment dike (impounded/reference) is given. Impoundment One was studied in 1990 and 1999 and Impoundments Two, Three, and Four were studied in 1996.

than in those of the unimpounded marsh, but mussel biomasses were comparable in the two areas. However, the density and biomass of *Geukensia* along the tidal creeks were much lower in Impoundment One and the unimpounded marsh than in the Headquarters Marsh below the dike. It was suggested that the abundance of *Geukensia* along the creek below the dike may be due to a downstream influence of impoundment (Peck and others 1994).

The densities of three amphipods in Impoundment One were significantly different from those in the reference marshes after 21 years of restoration. *Orchestia*, which prefers higher marsh elevations (Kneib 1982, Fell and others 1982) and *Uhlorchestia* were less abundant in Impoundment One than in the reference marshes, whereas *Gammarus*, which prefers lower, wetter conditions (Gable and Croker 1977, Kneib 1982), was more abundant in Impoundment One. *Gammarus* tended to be most abundant in areas of Impoundment One (transects 3E and 3W) which in 1976 contained two large unvegetated pannes with standing water (Sinicrope and others 1990) and which are still relatively wet with a few moderate size pools. On the other hand, *Melampus* tended to be less numerous in these former panne areas. While the density of *Philoscia*, which is found primarily in higher marsh regions (Fell and others 1982), was not significantly different in Impoundment One and reference marshes, this isopod tended to be less abundant above the breached impoundment dike. Thus the failure to achieve equivalency of macroinvertebrate populations after two decades appears to be related, at least in part, to marsh elevation. In 1984 the marsh surface 10–50 m above the dike was 5–10 cm lower than the reference marsh (Warren and others 1985); however, detailed studies of marsh elevations and flooding patters have not been done. Differences in elevation, which are likely the result of 30 years of marsh impoundment (Roman and others 1984), may be reflected in differences in vegetation and animal populations.

Although the densities of most of the crustaceans were different in the restoring and reference marshes, the mean densities of all of the crustaceans combined were not. Consequently, food resources for fish may be nearly comparable in these marshes, depending upon selectivity. In contrast, the population densities of *Orchestia, Philoscia*, and *Gammarus* in Impoundment Four at Barn Island (Figure 5), which was still dominated by stunted *Phragmites*, were comparable to those in the reference marsh below the dike after only nine years of renewed tidal flooding (Fell and others 2000, Warren and others 2001). At the same time, the densities of *Melampus, Geukensia*, and *Uhlorchestia* were significantly lower in the restoring marsh than in the reference marsh which appears to have a greater hydroperiod.

Peck and others (1994) used *Melampus* as an indicator species for the restoration of high marsh, but it now appears from more recent studies at Barn Island and elsewhere (Fell and others 2000, Warren and others 2001) that various benthic invertebrate populations may recover at different rates and in some cases independently of striking vegetational change. Therefore it is preferable when assessing restoration to examine a suite of marsh invertebrates that exhibit different patterns of distribution (see Wenner and Beatty 1988, Moy and Levin 1991, Scatolini and Zedler 1996).

Scatolini and Zedler (1996) found that epibenthic invertebrates (sampled with litter bags) were less abundant in a four-year-old created marsh than in a natural reference marsh in southern California. However, the assemblages of species and their relative abundances were fairly similar in the two marshes. The authors suggested that the differences may be related to coarser sediment, lower organic matter and sparse, shorter plant cover in the created marsh. Created marshes, like many restoring marshes, appear to require a relatively long time to achieve parity with reference marshes.

Twenty-one years after the reestablishment of tidal flooding, the tidal creek and mosquito-control ditches in Impoundment One exhibited a characteristic assemblage of marsh nekton which was similar to that below the dike. Fish species richness was the same in the restoring and reference marshes. *F. heteroclitus*, the numerically dominant species in both areas, was as abundant in Impoundment One as it was in marshes below the dike. In fact, the number caught in mosquito-control ditches was significantly greater in Impoundment One than in the reference marsh, whereas the numbers trapped in the tidal creek above and below the dike were not. The greater abundance of *F. heteroclitus* in the ditches of Impoundment One may be related, at least in part, to the presence of *Ruppia maritima* in the ditches above the breached dike (Lubbers and others 1990).

During 1999 fish were caught in unbaited minnow traps. Eight years earlier, limited sampling using blocking Fyke nets in mosquito-control ditches also indicated that the fish assemblage in Impoundment One resembled that in the Headquarters Marsh below the dike as well as that in a nearby unimpounded valley marsh (Allen and others 1994, Fell and others 2000). However, it appeared that *F. heteroclitus* may have been less abundant in the restoring marsh.

Sampling with Breder traps in 1995 (Fell and others 2000) and 1999 further showed that all of the common fishes of the creek and ditches use the flooded marsh surface during spring tides. In these studies, *F. heteroclitus* was equally abundant in the restoring and reference marshes. *Cyprinodon* was more abundant above the dike and *Menidia* was more numerous below it.

No sampling of fish was done until Impoundment One had been restoring for 13 years. However, other studies have shown that recovery of fish populations may be a relatively rapid process once tidal flooding is reestablished. In a Rhode Island marsh system the density, species richness and species composition of fishes and decapod crustaceans were similar in restoring and reference regions after only one year of renewed tidal flooding (Roman and others 2001). Similarly, Burdick and others (1997) found similar assemblages of fish in restored and reference regions of a New Hampshire marsh one month following the initiation of restoration. However, full use of restoring marshes by fishes for foraging, reproduction, and as refuges from predation may require longer periods of time.

Fewer *F. heteroclitus* were caught in minnow traps during the winter than during other seasons. Halpin (1997) also found this to be the case in a Rhode Island marsh system. The low number of captures during the winter may be the result of both a smaller resident fish population and a lower level of fish activity at this time of year. There may be a slight offshore movement of mummichogs during the colder months (Thomson and others 1971); however, this has not been well documented. Smith and Able (1994) showed that both large and small *F. heteroclitus* overwintered primarily in pools, 25–40 cm deep, in an unditched marsh system in New Jersey. During the winter this fish became scarce in intertidal and subtidal creeks and abundant in pools on the marsh surface. Such moderately deep pools were not present in the marshes at Barn Island. Since passive traps were employed in both studies, the fish had to actively explore and enter them.

To summarize, 21 years after breaching the dike, much of the area of Impoundment One at Barn Island was covered by *Spartina* grasses and other saltmarsh angiosperms. The densities of some marsh macroinvertebrates (*Melampus* and *Philoscia*) were not significantly different from those in the reference marshes below the dike. Other invertebrates (*Orchestia*, *Uhlorchestia*, and *Geukensia*) were less abundant and *Gammarus palustris* was more abundant in recovering Impoundment One. The fish assemblages above and below the dike were very similar. *F. heteroclitus*, the numerically dominant fish, was more abundant in the ditches of Impoundment One than in those of the reference marsh; however, the numbers of this fish caught in the tidal creek were not different in the two marsh areas. Furthermore, Brawley and others (1998) and Warren and others (2001) have shown that short-grass-marsh bird specialists (saltmarsh sharp-tailed sparrow and seaside sparrow) are now nesting in Impoundment One which is also used extensively by other wetland birds. Although Impoundment One exhibits many attributes and functions of tidal salt marshes, it is not yet fully recovered.

In conclusion, the studies at Barn Island, as well as others (Rozsa 1995, Simenstad and Thom 1996, Warren and others 2001), indicate that natural restoration of impounded marshes following the reintroduction of tidal flooding is a gradual process with various attributes and functions recovering at different rates.

Consequently resource managers and scientists should not rush to judgement concerning the success of restoration after only a few years. Full recovery relative to reference marshes, if it is ever achieved, may require more than two decades. In many cases, full structural and functional equivalency may not be a realistic goal, and an extensive recovery of salt marsh attributes and functions should be regarded as a successful outcome of restoration efforts. Furthermore, it appears that in the absence of a high correlation among attributes and functions one cannot reliably estimate either the rate or extent of marsh restoration (reclamation) from a few easily measured structural attributes (Oviatt and others 1977, Zedler and Lindig-Cisneros 2000). Long-term monitoring studies should be part of any restoration project and should assess benthic invertebrate populations and bird use as well as vegetation and nekton, in addition to physical attributes. Data from such studies not only serve to document restoration responses but also provide basic information on the process of restoration that is important for the planning of future restoration projects.

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